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DECLINE AND MORTALITY OF RED SPRUCE IN WEST VIRGINIA

CONTENTS

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DECLINE AND MORTALITY OF RED SPRUCE IN WEST VIRGINIA

by

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ABSTRACT

An evaluation of red spruce forests on the Monongahela National Forest and adjoining state and private lands in West Virginia was conducted in 1985. High altitude panoramic color-IR aerial photos and ground surveys were used to establish an inventory of healthy, dead, and declining red spruce. Forests with red spruce were stratified into three vegetation types and three mortality classes. Approximately 110,685 acres of forest land were classified as having a red spruce component and 1,603 acres as having mortality equal to or greater than 30 percent of the red spruce component. There are an estimated 96, 37, and 11 million cubic feet respectively of healthy, declining and dead red spruce in the state. Declining and dead trees represent 33 percent of the total red spruce volume. Statistical data are presented on the levels of red spruce decline and mortality for each vegetation type and mortality class. Symptoms and biotic agents associated with the decline are described.

INTRODUCTION

There have been recent reports of widespread decline and mortality of red spruce, Picea rubens, Sarg., throughout its natural range in the eastern United States. Quantitative evidence of the occurrence of a decline of red spruce was provided in a survey conducted in 1982 by Johnson and Siccama (1983). Weiss et al. (1985) conducted extensive aerial and ground surveys of portions of New Hampshire, New York, and Vermont in 1984 to document the status of mortality and decline of both red spruce and balsam fir, Abies balsamea, L., in those states. Tree ring analyses of red spruce from the northeastern United States and the central Appalachians indicate marked declines in growth since the early 1960's (Adams et al. 1985; Hornbeck and Smith 1985).

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Both anthropogenic and natural causes have been implicated in the recent decline of red spruce; however, to date no clear cause and effect relationship has been established. Although documentation of actual amounts of deposition of anthropogenic substances in the eastern United States is sparse, indications are that the mountains of West Virginia receive, on a weighted average, inputs of sulphur dioxide, nitrous oxides, acid precipitation and ozone that are among the highest in the eastern United States (Husar 1985). Therefore, if red spruce or other forest trees are injured by any of these substances, injury should be evident in West Virginia.

A survey of red spruce in West Virginia was undertaken in 1985. This survey was prompted by the discovery of large numbers of dead and dying red spruce on the Monongahela National Forest in 1983 (Mielke et al. 1984). Objectives of this survey were to:

1. Determine the present location and extent of red spruce forests in West Virginia.

2. Estimate the basal area, numbers of trees, and volume per acre of healthy, declining, and dead red spruce.

3. Determine the status and condition of natural regeneration of red spruce and other commercially important species.

4. Evaluate the feasibility of using high altitude panoramic aerial photography to identify and map red spruce forests and to quantify tree mortality.

DISTRIBUTION OF RED SPRUCE IN WEST VIRGINIA

Red spruce occurs in the east central part of West Virginia, physiographically characterized by parts of the unglaciated Allegheny Plateau and the Allegheny Mountains. The bulk of the red spruce forest is on the Monongahela National Forest, and to a lesser extent, intermingled state and private ownerships (Figure 1). In addition, many plantations of red spruce and Norway spruce, *Picea abies*, (L.), Karst., were established within the natural range of red spruce in West Virginia during the 1930's.

In the northern part of its range, red spruce is commonly associated with a mixture of northern hardwoods; eastern hemlock, *Tsuga canadensis* (L.) Carr.; eastern white pine, *Pinus strobus* L.; and balsam fir. The latter species is replaced by Fraser fir, *A. fraseri*, (Pursh), Poir., in the southern Appalachians. In West Virginia, red spruce occurs at elevations above about 3000 feet. It occurs in association with northern hardwoods at the lower elevations, eastern hemlock and hardwoods growing in drainages, and in nearly pure stands at elevations above about 3,800 feet. In West Virginia, balsam fir is restricted to four locations (Core 1966), and Fraser fir does not occur naturally. Except for the absence of fir, spruce stands in West Virginia are not compositionally distinct from comparable stands in the northeast or in the southern Appalachian Mountains (Stephenson and Clovis 1983).

Red spruce apparently was widely distributed in West Virginia during the last ice age. After the glaciers receded and the climate moderated, red spruce became restricted to the higher elevations. There were about 1.5 million acres of spruce forest when the first white settlers occupied this region. This area was steadily reduced by natural and man-caused factors to approximately 750,000 acres by 1865. In the ensuing 30 years, fires, insect and disease outbreaks, and logging reduced this area to about 225,000 acres (Hopkins 1899). By 1920 virtually the entire spruce type had been cut over (Clarkson 1978).

According to Hopkins (1899) extensive red spruce mortality caused by bark beetles occurred during two distinct periods, one from 1882 until about 1886; and another from 1890 until 1893. During the first period, mortality was attributed to an outbreak of a bark beetle, the four-eyed spruce beetle, *Polygraphus rufipennis*, Kirby. This outbreak was precipitated by the disturbing influences referred to earlier, together with severe droughts and storms, "all (of which) contributed to favorable conditions for the multiplication of the species and its numerous allies, and the consequent destructive invasion". The second period of mortality was apparently caused by another bark beetle, the southern pine beetle, *Dendroctonus frontalis*, Zimm., in combination with the four-eyed spruce beetle.

This series of events has produced the red spruce forests which occur in West Virginia today. The area the species occupies today is considerably reduced and the sites on which it grows have been altered by timber harvesting and fire.

METHODS

AERIAL PHOTOGRAPHY

High altitude panoramic aerial photography, taken by a NASA earth resources reconnaissance aircraft, was used to identify coniferous forest types believed to contain a red spruce component and to stratify these types into mortality classes. This photography was originally taken for a multistate survey of hardwood defoliation caused by the gypsy moth, *Lymantria dispar*, L. Photography was acquired during June and July 1984 and included all or portions of Maryland, New Jersey, Pennsylvania, and West Virginia (NASA Mission Number 84-121). All of the high altitude conifer forest in West Virginia was included on portions of four flight lines (lines 15, 16, 17, and 18) of this mission (Figure 1). Photography was flown with a NASA ER-2 aircraft from a flying height of ca. 65,000 feet above mean sea level. The camera system was an Itek Iris-II[2/] panoramic camera modified to cover a 90 degree field of view. Kodak SO-131 High Definition aerial Ektachrome color-IR film was used. Nadir photo scale was ca. 1:30,000.

[2/] Mention of commercial products is for convenience only and does not imply endorsement by USDA Forest Service.

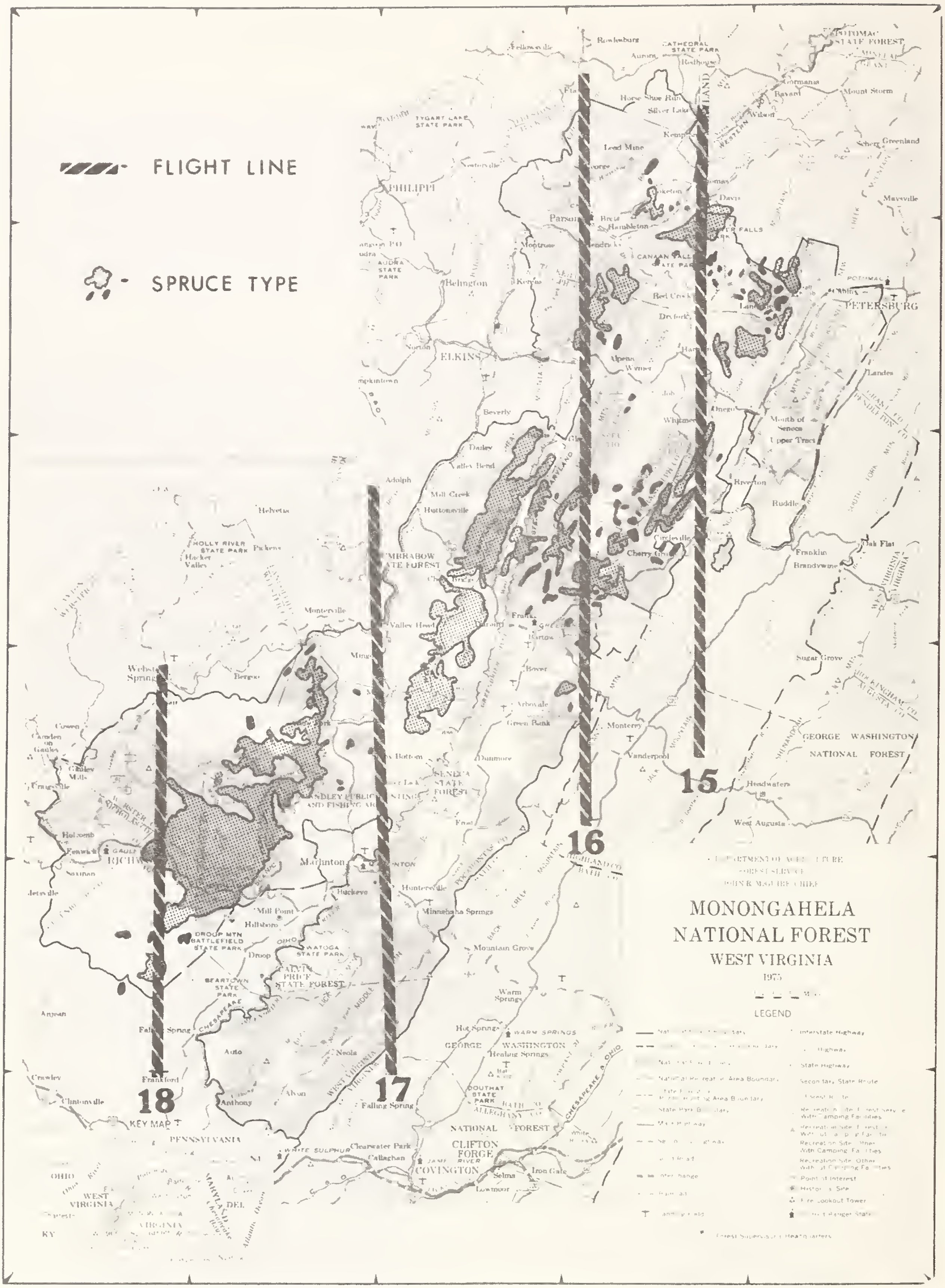

Figure 1. Aerial photo flight lines and distribution of red spruce on the Monongahela National Forest and adjoining state and private lands in West Virginia.

PHOTO INTERPRETATION

VEGETATION CLASSIFICATION - Forested areas containing conifers were identified on the aerial photos and initially classified into four vegetation classes:

SPRUCE - Areas with $>$50 percent of the stems in the overstory red spruce.

MIXED-WOOD - Areas with $\geq$25 percent but $\leq$50 percent of the stems in the overstory red spruce.

PLANTATIONS - Conifer plantations.

OTHER CONIFERS - Native stands of eastern white pine; yellow pines, *Pinus rigida*, Mill., *P. virginiana*, Mill., and *P. pungens*, Lamb.; or eastern hemlock.

A preliminary classification of coniferous vegetation was conducted on four photos, frames 304, 308, 314, and 318 of flight line 16. A sample of 150 polygons of more or less homogeneous vegetation containing a conifer component was identified on these photos. Polygons were selected so as to be representative of the entire frame. The location of each polygon was transferred to a 1:24,000 USGS topographic map and was classified into one of the four vegetation classes described above. Characteristics used to classify vegetation types were elevation, crown texture, amount of hardwood cover, character of stand margins, topographic position and foliage color.

Sixty-six of the polygons classified on the aerial photos were ground checked during April 1985. These polygons were classified according to the same standards used on the aerial photos. Comparison of aerial photo and ground classification of this sample provided a basis for development of photo interpretation standards for the entire survey area.

MORTALITY CLASSES - Polygons identified as spruce or mixed-wood were further stratified into three mortality classes:

1. Light - $<$10 percent of the standing conifers dead or dying.

2. Moderate - 10-30 percent of the standing conifers dead or dying.

3. Heavy - $>$30 percent of the standing conifers dead or dying.

These were the same strata used to classify mortality in an inventory of spruce and fir decline and mortality conducted in portions of New Hampshire, New York, and Vermont (Weiss et al. 1985).

STRATIFICATION - Following the preliminary aerial photo classification and ground checks, all polygons with a red spruce component were identified on the aerial photos. Each polygon was assigned to a vegetation/mortality class.

Their locations were transferred to 1:24,000 scale USGS topographic maps, using a Bausch and Lomb zoom transfer scope, and the area of each stand was measured with a Numonics digitizer.

GROUND DATA ACQUISITION -

SELECTION OF GROUND POINTS - The primary ground sampling unit was a polygon. This was an area delineated on the aerial photos which was homogeneous with regard to vegetation type and mortality class. Within a stratum, polygons were selected for ground sampling using simple random selection without replacement. A minimum of 10 and a maximum of 30 polygons per stratum were selected for ground sampling. Strata were sampled at a rate designed to provide a 10 percent standard error of the mean for estimates of basal area, cubic foot volume, and numbers of trees per acre.

There were some exceptions to the sample selection rule. A total of 44 polygons could not be classified into mortality strata because of film exposure problems. These were treated as a separate mortality stratum (unclassified) and 18 polygons were ground sampled. In addition, all polygons greater than 1000 acres were ground sampled.

The total number of sample points per polygon depended on polygon area. Three sample points were established in polygons of 15 acres or less, 5 in polygons up to 1,000 acres, and 7 or 8 in polygons of greater than 1,000 acres. Points were located randomly in patterns which optimized coverage of each respective polygon. Points were placed a minimum of 2 chains apart in the smaller polygons and a minimum of 5 chains apart in polygons of 15 acres and larger.

DATA COLLECTION - Data were collected using 10 BAF variable radius plots in the mixed wood type, and 20 BAF variable radius plots in the conifer and plantation types. Data were collected on all trees $\geq$1 inch dbh. For each red spruce, data collected on the variable plot included dbh by 2 inch class for trees >5 inches dbh and 1 inch class for trees $\leq$5 inches dbh, number of 8 foot logs to a minimum 9 inch top diameter, crown class, and tree condition. Tree condition was a visual assessment of the bole and crown. Trees were classified as healthy if they had greater than 40 percent live crown ratio and no signs of major bole injury or defect. Live crown ratio was defined as the ratio of live crown to total tree height, visually restoring gaps and dead or dying limbs with extant live limbs. Live trees with live crown ratios less than 40 percent were classified as declining. Specific reasons for decline (suppression, branch canker, snow breakage, heartrot, etc.) were noted. Only dead trees with at least their second order branches intact were classified as dead. Old dead trees with few or no main branches were ignored. Only dbh and species was recorded for all other tree species.

The numbers of seedlings and saplings of spruce and other commercially important species were recorded at the center of the variable plot in a 1/1000 acre fixed radius plot.

RESULTS

QUALITY OF AERIAL PHOTOS

An exposure gradient occurred across each of the photo frames. A portion of each photo east of nadir was slightly underexposed, the mid-section was optimally exposed, and the region west of nadir was slightly overexposed. This gradient was most apparent on flight lines 17 and 18 which covered the westernmost portions of the target area. The exposure gradients caused a drastic shift in the color of coniferous vegetation from a dark to medium red-purple hue in the optimal and underexposed segments of each frame to a light purplish-blue in the overexposed regions. Spruce stands which appeared on the easternmost portion of photos on flight line 17 were so dark that tree mortality classes could not be stratified.

VEGETATION/MORTALITY CLASSIFICATION

Of the characteristics used to identify the coniferous vegetation types on high altitude color-IR photos, foliage color was the least reliable character because of the color variation associated with the exposure gradients. Dead trees were visible as hues of blue-gray in all but the underexposed portions of photos on flight lines 17 and 18.

Comparison of the preliminary aerial photo classification with ground data using an error matrix showed an overall agreement of nearly 72 percent (Table 1). The ground checks revealed two conditions which were not accounted for in the original descriptions of conifer vegetation classes. A considerable proportion of the plantations on the Monongahela National Forest are red spruce plantations. This is especially true on the Greenbrier District. The original vegetation classification would have eliminated these plantations from the decline and mortality inventory. In addition, we found that most stands classified as mixed wood or conifer above 3000 feet contained a red spruce component, usually in association with eastern hemlock.

As a result of these observations we redefined the vegetation classes (Table 2) and revised the photo interpretation standards for vegetation classification (Table 3).

Table 1 - Error matrix of preliminary aerial photo classification of coniferous vegetation types on high altitude panoramic aerial photos versus ground classification - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Vegetation Class on Ground Plots (Number of Polygons)	Vegetation Class on Aerial Photos (Number of Polygons)				
	Other	Mixed Wood	Spruce	Plantation	Subtotal
Other	2a	0	0	0	2
Mixed Wood	0	7a	1	0	8
Spruce	10	1	9a	0	20
Plantation	6	0	1	29a	36
Subtotal	18	8	11	29	47/66=71.2%

a - Denotes agreement between aerial and ground classification

Table 2 - Vegetation types and mortality classes used in final classification of forests with a spruce component - Monongahela National Forest, West Virginia - 1985.

Vegetation Type	Mortality Class
Conifer with Spruce Component (C) (>50% Conifer)	1 - <10% 2 - 10%-30% 3 - >30%
Mixed Wood with Spruce Component (M) (≥25% but ≤50% Conifer)	1 - <10% 2 - 10%-30% 3 - >30%
Spruce Plantation (P)	1 - <10% 2 - 10%-30% 3 - >30%

Table 3 - Decision key for identification of conifer stands with a red spruce component on small scale panoramic CIR aerial photographs - Monongahela National Forest and adjoining lands, West Virginia - 1985.

1.	Conifer stands below 3,000 feet	Other
1a.	Conifer stands above 3,000 feet	2
2.	Stand boundaries irregular - generally conform to a topographic feature such as a drainage or ridge (natural stands)	3
2a.	Stand boundaries more or less distinct, a sharp line of demarkation exists between conifer stand and adjoining hardwoods, often in distinct blocks and adjacent to a road (plantations)	4
3.	Conifer component occupies greater than 50 percent of the canopy	Conifer (red spruce or hemlock/red spruce)
3a.	Conifer component occupies between 25-50 percent of the canopy	Mixed Wood (red spruce, eastern hemlock, hardwoods)
4.	Trees occur in visibly distinct rows	Red Pine
4a.	Trees not in visibly distinct rows	Red and/or Norway Spruce

A total of 110,685 acres of forest land was classified as having a red spruce component (Table 4). Approximately 75 percent of the area was on the Monongahela National Forest, 20 percent on private lands within the Forest proclamation boundary, and 5 percent on other state or private lands (Figure 1). Area of light mortality comprised 86.5 percent of the total, 5.7 percent was moderate, and 1.5 percent heavy. Approximately 6.5 percent of the forest area classified as having a spruce component could not be classified into mortality strata because of film exposure problems. Most of this area was on Cheat Mountain and Shavers Mountain and was primarily private land.

There were 142 polygons in the ground survey totaling 31,824 acres. Of these, 11 polygons, totaling 510 acres (1.7 percent) had no spruce component. Five of the 11 polygons were plantations (Table 5).

The agreement between photo interpretation classification and the ground data was best for the conifer vegetation type, and poorest for the plantation type. Photo classification of the conifer type was 85.7 percent correct and

Table 4 - Forest area with a red spruce component by vegetation type and mortality class, as determined from interpretation of high altitude panoramic CIR aerial Photographs - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Vegetation Type	Mortality Class (Acres) Light	Moderate	Heavy	Unclassified	Total
Mixed Wood	61,944	2,576	1,041	2,052	67,613
Conifer	31,936	3,718	562	5,119	41,335
Plantation	1,698	39	0	0	1,737
Total	95,578	6,333	1,603	7,171	110,685

the mixed wood type was 56.7 correct. Only 41.7 percent of the plantation type was correctly identified on the photography. This was due to the misclassification of red pine and other conifer plantations as red spruce plantations. Due to the high classification error associated with plantations, they cannot be regarded as reliable. Agreement improves considerably for the conifer and mixed wood types if the bounds for the proportion of spruce are slightly broadened (Table 6).

The per acre values and their standard errors were computed based on polygon means. No estimate was made of the within polygon component of variance. Polygons over 1,000 acres in size were always measured, computation of means and standard errors were then adjusted. The standard errors reported in this paper are smaller than the true standard errors for this sample. The means however, remain unbiased.

STATUS OF DECLINE AND MORTALITY

In the mixed wood type, the volume, basal area and numbers of trees per acre of declining and dead spruce increase in the higher mortality classes. While some standard errors are large, the trend is clear and indicates a general concurrence with the photo classification. The volume, number of trees, and basal area per acre of healthy trees is lower in the heavy mortality class, but there is little difference between the light and moderate mortality classes (Table 7). In general, one would expect this relationship, assuming stocking levels are relatively uniform throughout the type (as the volume etc. of healthy trees goes up, the volume etc. of declining and dead trees goes down and vice versa).

This relationship is even clearer in the conifer type except for the lack of greater numbers of dead trees per acre in the higher mortality classes (Table 8). However, the volume and basal area per acre of dead trees do increase in the higher mortality classes, suggesting that on the photography the size of dead trees influenced the classification of polygons into their

Table 5 - Area ground sampled which did not contain a spruce component - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Vegetation Type	No. of Polygons Classified	No. of Polygons Sampled	Acres Ground Sampled	Acres Ground Sampled With no spruce Component (%)	No. of Polygons Ground Sampled With no Spruce Component
Mixed Wood	636	67	19,398	312(1.6)	5
Conifer	428	63	11,788	44(.4)	1
Plantation	58	12	638	154(24)	5
Totals	1,122	142	31,824	510(1.6)	11

Table 6 - Agreement between photo interpretation and ground classification of vegetation types with a spruce component - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Vegetation Type	Percent Spruce Bounds (Ground Data)		Percent Agreement
Conifer	>50		85.7
	>45	(-5%)	90.5
Mixed Wood	≥25-≤50		56.7
	≥20-≤55	(±5%)	70.2
	≥15-≤60	(±10%)	83.6
Plantation	>50		41.7

Table 7 - Mean volume, number of trees, and basal area per acre of healthy, declining, and dead red spruce ≥ 5 inches dbh in the mixed wood type - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Tree Condition	Mortality Class			
	Light	Moderate	Heavy	Unclassified
Healthy				
Volume[1]	499.67±68.89[2]	572.68± 72.45	348.38±22.13	387.38±113.19
Trees/Acre	51.22± 7.41	61.67± 7.36	46.81± 7.25	121.28± 36.28
BA/Acre	22.36± 2.93	29.21± 3.24	18.00± 1.47	24.50± 6.14
Declining				
Volume	190.03±26.23	252.26± 36.06	498.00±50.54	103.63± 34.08
Trees/Acre	16.71± 2.23	29.18± 5.37	48.82± 7.12	37.97± 12.36
BA/Acre	9.14± 1.16	12.21± 1.61	25.13± 2.63	7.00± 2.23
Dead				
Volume	76.30± 9.67	78.63± 18.15	178.25±10.57	26.13± 7.65
Trees/Acre	14.83± 4.00	15.42± 4.72	50.13±12.60	10.38± 3.50
BA/Acre	3.94± 0.49	4.21± 0.95	11.25± 0.97	2.13± 0.64
Total				
Volume	766.00±91.17	903.58±103.30	1024.63±58.27	517.13±149.89
Trees/Acre	82.76±11.21	106.26± 13.27	145.75±22.99	169.63± 49.09
BA/Acre	35.44± 3.86	45.63± 4.48	54.38± 3.85	33.63± 8.70

[1]/Cubic foot volume, trees per acre, and basal area per acre computed using SILVAH (Marquis et al. 1984).
[2]/± one standard error of the mean.

Table 8 - Mean volume, number of trees, and basal area per acre of healthy, declining, and dead red spruce $\geq$5 inches dbh in the conifer type, type - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Tree Condition	Mortality Class			
	Light	Moderate	Heavy	Unclassified
Healthy				
Volume1/	1492.97±168.01 2/	1460.24±208.05	321.80± 37.53	1403.30±280.56
Trees/Acre	283.04± 27.85	184.51± 51.48	54.94± 10.02	336.38± 78.87
BA/Acre	89.22± 8.90	72.65± 11.52	17.50± 1.98	76.30± 9.81
Declining				
Volume	537.79±108.25	962.12±116.25	1066.40± 88.65	492.10±160.84
Trees/Acre	99.77± 17.58	99.96± 12.64	145.47± 20.03	45.02± 12.58
BA/Acre	29.04± 5.19	46.82± 5.84	57.30± 5.15	23.00± 6.98
Dead				
Volume	120.01± 26.25	363.35±108.88	433.30± 42.40	155.40± 54.21
Trees/Acre	125.25± 23.67	58.88± 16.66	105.20± 13.34	46.30± 15.28
BA/Acre	13.60± 2.25	19.06± 5.12	28.50± 2.69	9.70± 3.25
Total				
Volume	2150.77±253.62	2785.71±242.64	1821.50±108.86	2050.80±410.83
Trees/Acre	508.06± 51.73	343.35± 56.35	305.60± 39.51	427.70± 72.05
BA/Acre	131.80± 13.43	138.53± 12.38	103.30± 7.12	109.00± 15.69

1/Cubic foot volume, trees per acre, and basal area per acre computed using SILVAH (Marquis et al. 1984).

2/± one standard error of the mean.

Table 9 - Mean volume, number of trees, and basal area per acre of healthy, declining, and dead spruce in plantations - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Tree Condition	Mortality Class	
	Light	Moderate
Healthy Spruce	2/	3/
Volume1/	1195.55±367.00	2317.00
Trees/Acre	313.20±107.18	745.36
BA/Acre	72.18± 22.03	153.00
Declining Spruce		
Volume	50.00± 28.00	316.00
Trees/Acre	4.62± 2.40	101.64
BA/Acre	2.36± 1.34	20.00
Dead Spruce		
Volume	7.18± 6.44	252.00
Trees/Acre	5.27± 3.35	68.00
BA/Acre	0.72± 0.46	17.00
Totals		
Volume	1252.73±380.27	2885.00
Trees/Acre	323.09±108.78	915.00
BA/Acre	75.27± 22.60	190.00

1/Cubic foot volume, trees per acre, and basal area per acre computed using SILVAH (Marquis et al. 1984).
2/One standard error of the mean.
3/Only one area of moderate mortality was classified.

Table 10 - Proportion of red spruce component $\geq$ 5 inches DBH by tree condition, vegetation and mortality classes - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Vegetation	Condition	Proportion of Number of Trees/Acre by Mortality Class			
		Light	Moderate	Heavy	Unclassified
Mixed Wood	Healthy	62.01	58.04	32.22	71.50
	Declining	19.98	27.45	33.49	22.38
	Dead	18.01	14.51	34.39	6.12
Conifer	Healthy	55.96	53.73	17.98	78.65
	Declining	19.52	29.12	47.60	10.53
	Dead	24.52	17.15	34.42	10.82
Plantation	Healthy	96.94	81.46	---	---
	Declining	1.43	11.11	---	---
	Dead	1.63	7.43	---	---

respective mortality classes. There is less total volume per acre in polygons with heavy mortality. The values for spruce plantations have excessively high standard errors, and there was only one sample in the moderate mortality class (Table 9).

The total cubic foot volume, basal area, or number of red spruce on forest land classified as having a red spruce component in West Virginia can be estimated by combining the per acre data for all vegetation types (Tables 7, 8, and 9) and expanding them over the entire area (Table 4). This provides estimates of 96, 37, and 11 million cubic feet of healthy, declining, and dead red spruce in the state, respectively. Declining and dead trees represent 33 percent of the total volume of red spruce in the area.

On a relative basis, up to 82 percent of the spruce component of the conifer stands was either dead or declining (Table 10), however, only a small proportion of the total population of spruce forest is affected by this high a level of damage.

The majority of red spruce basal area and volume per acre was in the pole and small sawtimber size classes. The majority of trees per acre was in the sapling and pole size classes. While the distribution of basal area, trees per acre, and volume by size class is expectedly nonuniform, the numbers of dead and declining trees as a percent of the total in each respective size class are remarkably similar, ranging from 30.3 percent to 47.6 percent for all categories in each size class (Table 11 and Figures 2, 3, and 4).

Table 11 - Mean basal area, trees and volume per acre of healthy and dead and declining red spruce by size class - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Size Class	Basal Area (Square Feet)		Number of Trees Per Acre		Cubic Foot Volume	
	Healthy	Dead and Declining	Healthy	Dead and Declining	Healthy	Dead and Declining
			Number (%)			
Saplings (1.0-5.5 in.)	3.81 (51.9%)	3.49 (47.6%)	60.18 (53.2%)	52.97 (46.8%)	0	0
Poles (5.5-11.5 in.)	22.03 (56.0%)	17.32 (44.0%)	73.38 (58.1%)	53.01 (41.9%)	385.54 (55.3%)	311.76 (44.7%)
Small Sawtimber (11.51-17.5in.)	18.42 (67.1%)	9.05 (32.9%)	18.99 (67.2%)	9.25 (32.8%)	422.79 (68.3%)	196.54 (37.9%)
Medium Sawtimber (17.51-23.5in.)	4.40 (69.7%)	1.91 (30.3%)	1.98 (65.1%)	1.06 (34.8%)	97.87 (64.1%)	54.82 (37.9%)
Large Sawtimber (>23.5in.)	.70 (62.5%)	.42 (37.5%)	.20 (64.5%)	.11 (35.5%)	18.71 (62.2%)	11.36 (37.8%)
Totals	49.4 (60.5%)	32.2 (39.5%)	153.7 (56.9%)	116.4 (43.1%)	924.9 (61.7%)	574.5 (38.3%)

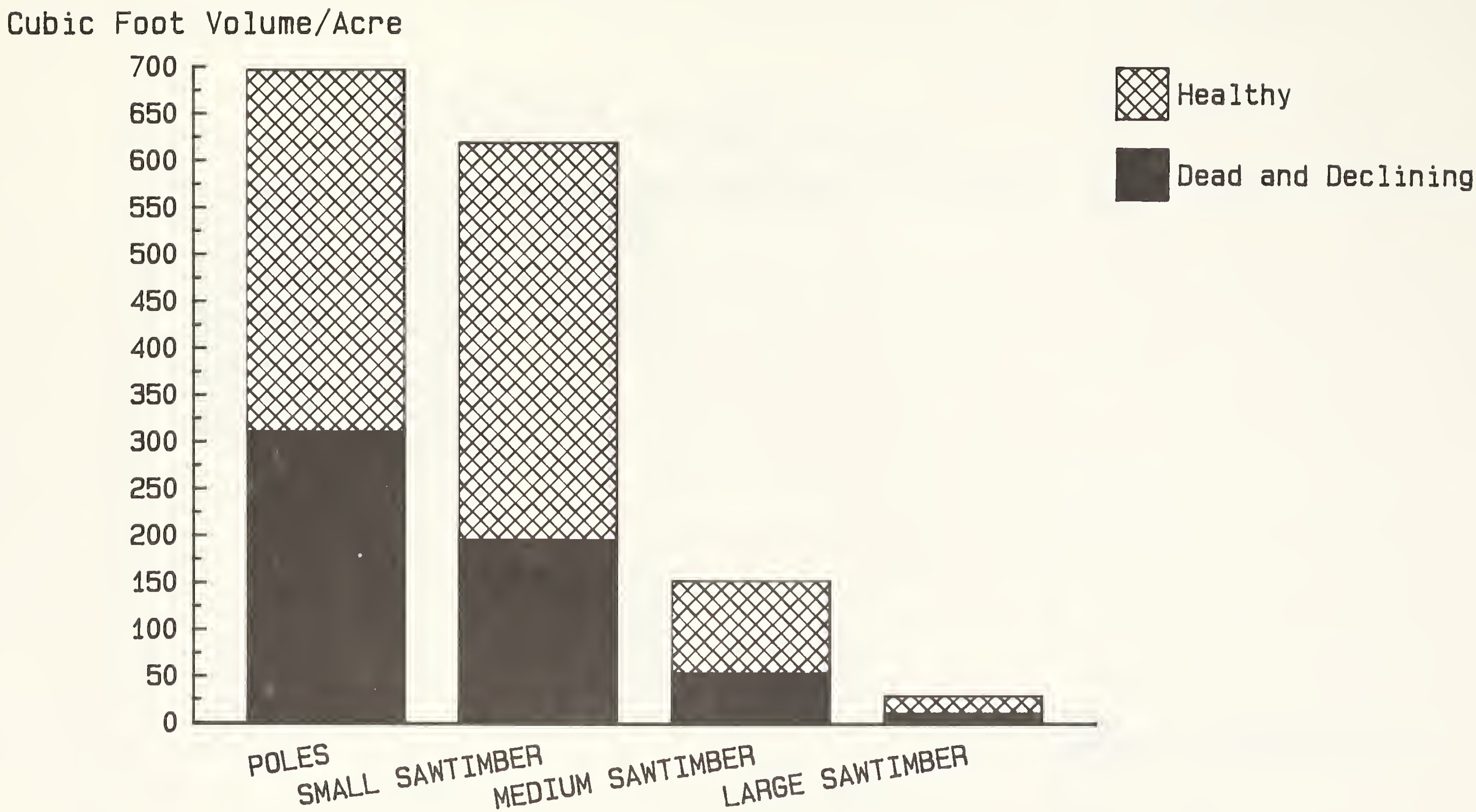

Figure 2. Cubic foot volume/acre of healthy, declining, and dead red spruce by size class - Monongahela National Forest and adjoining lands, West Virginia - 1985.

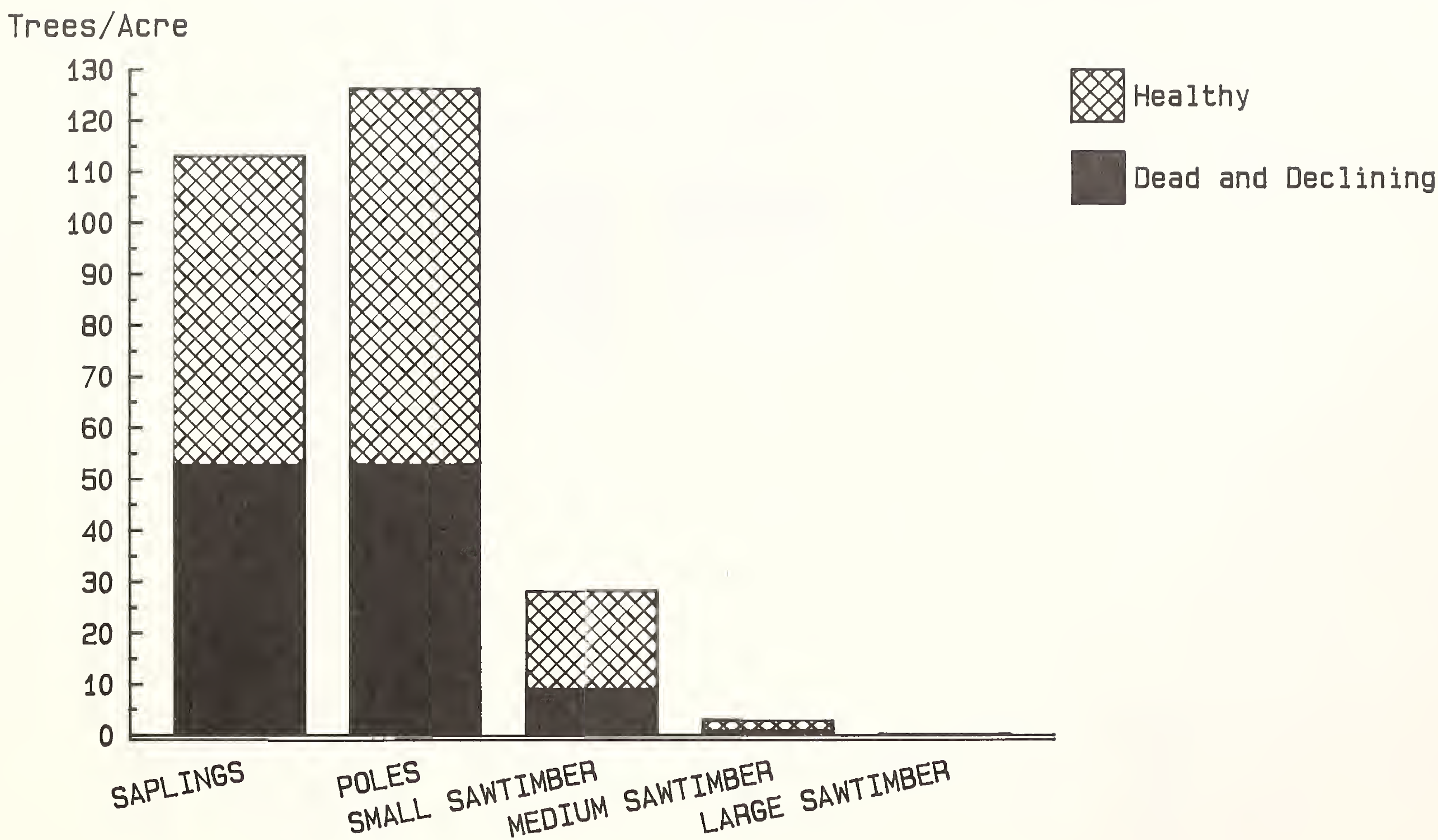

Figure 3. Trees/acre of healthy, declining, and dead red spruce by size class - Monongahela National Forest and adjoining lands, West Virginia - 1985.

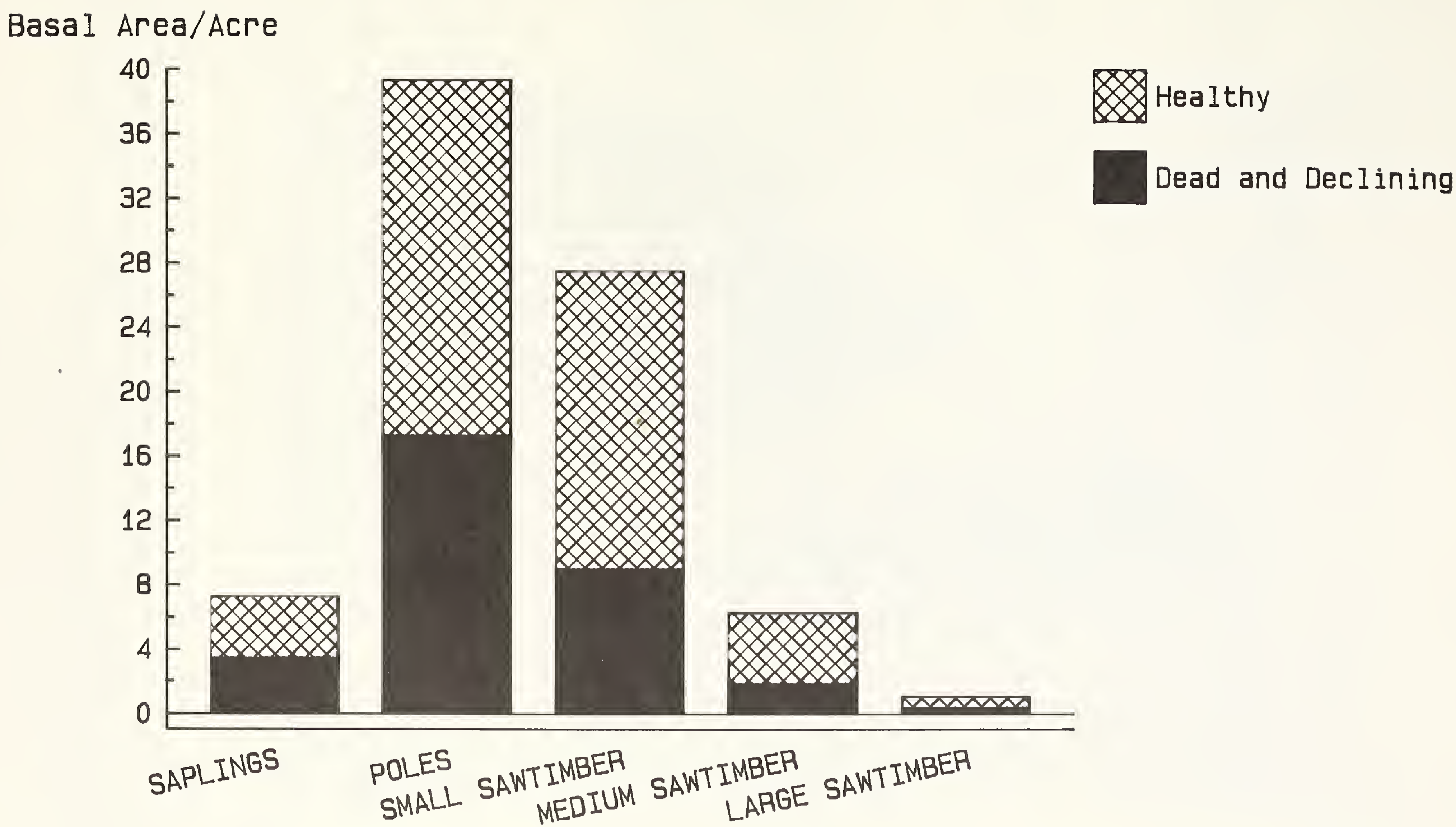

Figure 4. Basal area/acre of healthy, declining, and dead red spruce by size class - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Table 12 - Number of seedlings and saplings ($\geq$6" tall and <5" dbh) per acre by vegetation type and mortality class - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Species	Vegetation and Mortality Class									
	Mixed Wood				Conifer				Plantation	
	Light	Mod.	Heavy	Un-class	Light	Mod.	Heavy	Un-Class	Light	Mod.
Red Spruce	1991 $\pm$171[1/]	3067 $\pm$517	4267 $\pm$ 555	1317 $\pm$417	3105 $\pm$814	7000 $\pm$1685	8715 $\pm$2237	15500 $\pm$4946	30 $\pm$27	1800
Other Commercial Species	2387 $\pm$397	1913 $\pm$203	1075 $\pm$154	2450 $\pm$443	1065 $\pm$518	845 $\pm$249	960 $\pm$229	1705 $\pm$ 855	303 $\pm$243	800

1/$\pm$ one standard error of the mean.

The numbers of red spruce seedlings and saplings increase with increasing levels of overstory mortality in both the mixed wood and conifer types (Table 12). This is in agreement with data from Weiss et al. (1985) for red spruce in the northeast. Red spruce regeneration was abundant throughout the survey area and seems to respond favorably to increased levels of incident light created by a declining and dying overstory. Whatever the causes of overstory decline and mortality, the regeneration remains visibly unaffected. Regeneration of other species was more abundant in the mixed wood type than in the conifer type. This is to be expected because there are greater numbers of other species present in the overstory of the mixed wood type.

SYMPTOMS OF DECLINE AND ASSOCIATED BIOTIC AGENTS

Declining red spruce were defined as trees having live crown ratios of <40 percent (Figure 5). Most saplings and some pole size trees that were declining were doing so because of suppressed crowns. The primary reason for the decline condition of crowns in the larger size classes was the occurrence of branch mortality initiated as either "branch dieback", mortality from branch tips progressing inward toward the base; or "branch flagging", defined as mortality of second and third order twigs nearer the base of a branch progressing outward and creating a tuft or flag of live foliage on branch ends. Both branch dieback and flagging symptoms can result in dead branches. Another symptom was a copious resin flow from branches that was visible from the ground. This was recorded as "branch canker".

A total of 1,059 declining spruce were evaluated on 142 plots. There were 99 saplings of which 45 (45 percent) were suppressed, as were 14 out of 517 (3 percent) pole sized trees. Branch dieback, flagging, and cankers accounted for the symptoms observed in 502 out of 1,059 (47 percent) declining trees. A total of 326 of 1,059 (31 percent) of declining trees were not associated with a readily identifiable symptom or causal agent (Table 13).

Figure 5. Declining red spruce on the Monongahela National Forest, West Virginia.

Table 13 - Number of declining red spruce by symptom class and tree size class - Monongahela National Forest and adjoining lands, West Virginia - 1985.

Size Class	Number Examined	Symptom-Number of Trees (%)								
		Live Crown Ratio 40% [a]	Branch Dieback (BD)	Branch Canker (BC)	Suppression	Branch Flagging (BF)	Defective Bole	BD + BC	BC + BF	BD + BF
Saplings (1.0-5.5in)	99	33(33)	15(15)	1(1)	45(45)	0	1(1)	4(4)	0	(0)
Poles (5.51-11.5in)	517	204(39)	190(37)	49(9)	14(3)	1(1)	3(1)	53(10)	3(1)	(0)
Small Sawtimber (11.51-17.5in)	252	55(22)	122(48)	21(8)	(0)	4(2)	1(1)	47(19)	2(1)	(0)
Medium Sawtimber (17.51-23.5in)	133	30(23)	48(36)	14(11)	(0)	2(2)	2(2)	35(26)	1(1)	1(1)
Large Sawtimber (>23.5in)	58	4(7)	20(35)	12(21)	(0)	3(5)	(0)	18(31)	1(2)	(0)
TOTALS	1059	326(31)	395(37)	97(9)	59(6)	10(1)	7(1)	157(15)	7(1)	1(1)

[a] No other symptoms were readily visible.

As part of a cooperative survey conducted by West Virginia University and the Morgantown Forest Pest Management Field Office to identify insects and diseases associated with the decline and mortality of red spruce, the fungus, Valsa kunzei, Fr. (pycnidial stage = Cytospora kunzei, Sacc.), was consistently found associated with symptomatic branches of declining crowns. Other fungi of lesser or undetermined pathogenicity also were found. In addition, all dead and declining trees, and trees classified as healthy (>40 percent live crown ratio) (N=55) had one or more crown symptoms associated with V. kunzei; including branch dieback, flagging, heavy resin flow, or staining in the bark and cambium. Pycnidial fruiting bodies also were found, however, they and stain can be seen only on close inspection. This suggests that declining trees with live crown ratios <40 percent (Table 12) could be associated with other V. kunzei caused symptoms. If they are, as many as 828 of 1,059 (78 percent) of all declining trees may have symptoms attributable to V. kunzei. Also, declining trees examined in the above mentioned survey had extensive fine feeder root mortality and fewer mycorrhizae as compared to healthy trees. Root disease caused by Armillaria mellea, Vahl. ex Fr., and Scytinostroma (Corticium) galactinum (Fries), Donk, were found only to a limited extent, and were usually on sites with poor drainage. All dead trees and some severely declining trees had been attacked by the four-eyed spruce beetle, Polygraphus rufipennis.

DISCUSSION AND CONCLUSIONS

There are approximately 110,685 acres of forest land with a red spruce component in West Virginia today. Approximately 37 percent of this area is of a vegetation type in which at least half of the trees are conifers. This vegetation type occurs at the highest elevations in this state and is presumably a pure or nearly pure red spruce forest. Sixty-one percent of the area was classified as a mixed wood type which contains a sizeable proportion of hardwoods. The conifer component of this type may be either red spruce or eastern hemlock with the proportion of eastern hemlock increasing with decreasing elevation. Only about 7 percent of the total area of spruce type in West Virginia currently has greater than 10 percent mortality. However approximately 35 percent of the red spruce basal area, 40 percent of the numbers of trees, and 33 percent of the volume in the state is either dead or declining. The primary criteria for rating a tree as "declining" was a visual assessment of crown vigor.

High altitude panoramic aerial photography was only partially effective as a tool for identifying forested areas with a red spruce component and classifying these stands into mortality strata. The small scale precluded reliable separation of conifers by species. Eastern hemlock, which frequently occurs in mixture with red spruce in West Virginia, could not be differentiated from red spruce on these photos. Consequently, the conifer component of many of the stands classified as mixed-wood was predominantly eastern hemlock with an occasional red spruce.

In addition, attempts using panoramic aerial photography to stratify vegetation types into three mortality strata were only moderately successful. Ground data on levels of decline and mortality show little if any differences between the light and moderate classes. The heavy mortality stratum, however, did have higher levels of mortality. In the conifer type, the volume and basal area per acre of dead trees increased in the moderate and heavy mortality classes, however the number of dead trees per acre decreased. This suggests that a small number of large dominant dead trees were thought by photo interpreters to represent a higher level of mortality.

Exposure gradients present in the photos also contributed to the difficulty of separating vegetation types and classification of mortality strata. If subtle differences in crown shape, foliage texture, and color between red spruce and eastern hemlock are resolved on small scale color-IR aerial photos, they were masked by the variability caused by the exposure gradients. Approximately 6.5 percent of the total area of forest cover classified as having a spruce component could not be stratified into mortality classes because the underexposed segments of film could not be resolved on dead trees.

The primary symptom associated with declining red spruce in the larger size classes was branch mortality. The fungus _Valsa kunzei_ was commonly associated with this mortality. _V. kunzei_ is pathogenic to many conifers and can be

especially disfiguring and even fatal to red and Norway spruce (Waterman 1955). In most cases, however, spruce must first be predisposed by an environmental stress, in particular, winter injury and drought, before V. kunzei can successfully attack (Lavallee and Bard 1978; Schoeneweiss 1983; Waterman 1955). This fungus was the most frequent reason for crowns of trees of larger size classes being classified as declining. Growth rates of severely infected trees are probably also affected. While no extensive growth ring analyses were conducted, the overall assessment of declining crowns in this survey suggests that branch infection by V. kunzei may be contributing to the reported growth trend decline in West Virginia (Adams et al. 1985).

In photographs taken during the period 1870-1920 (Clarkson 1975), the condition of some red spruce crowns appears similar to those of declining red spruce observed during this survey. This suggests that the current presence of V. kunzei may not be a new phenomenon, although its level of severity may be. Whether growth rates were also declining during that period is not known. It is possible that the chemical climate in West Virginia in recent times has predisposed spruce trees to infection by V. kunzei or perhaps aggravated the disease condition. Also, recent periodic droughts and severe winter weather may be contributing to the possible increased levels of infection.

The amount of decline and mortality as a percent of the total in each size class is similar for all size classes. This suggests that overall mortality and decline is not related to tree age. The reasons for low crown vigor, i.e., decline, in the smaller and larger size classes do differ however. Most of the saplings and some poles were suppressed, while sawtimber was more often infected by V. kunzei. Also, spruce is a shade tolerant tree and will often grow slowly in the understory for many years before being released. It will also slow down in radial growth under increasing competition, particularly under unmanaged conditions. Therefore, the age/diameter relationship can vary from stand to stand.

The extensive timber harvesting and associated fires which occurred around the turn of the century may have had some long term deleterious effect on the growth potential of those sites now supporting spruce, including the ability of sites to carry individual spruce for the 300+ years they can live. In the heavy mortality class of the conifer type there are fewer total healthy, declining and dead spruce per acre, less basal area, and volume per acre. This suggests that some intrinsic site factor may be contributing to the higher levels of mortality and lower productivity exhibited there.

If air pollution is to be considered as the primary cause for the decline and mortality of red spruce in West Virginia, there must also be some explanation of the apparent lack of decline symptoms on the red spruce regeneration which is presently abundant and thriving. Whatever the cause or combination of causes responsible for the decline and mortality of the red spruce overstory in West Virginia, this survey adds to the body of information describing its existence.

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